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Review paper

REVIEWING THE PHOTOVOLTAIC POTENTIAL OF BIJELJINA IN THE REPUBLIC OF SRPSKA

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Abstract. *To estimate PV potential of Bijeljina, PVGIS and SOLARGIS databases were used. The results showed that Bijeljina municipality has an average daily PV power potential of 3.50 kWh/kWp, thus belonging to areas with the favorable mid-range PV power potential values. Average levelized cost of electricity is $0.12/kWh, consequently making PV technologies in Bijeljina also economically competitive with conventional power-generating sources. In the light of the rapid development of photovoltaic technology, this paper gives a critical review of previous studies and suggests that the application of PV technologies has become even more attractive. High-efficiency PV modules and grid inverters were tested on examples of roof-mounted PV systems and ground-mounted PV system using specialized PVSYST software. Comparison of the obtained results with previous studies gave a clear picture with advantages of these new solutions, and further support for PV technologies utilization.*

Key words: *Photovoltaics (PV), solar irradiation, PV module, PV solar power plant, PV power potential, Bijeljina*

1. INTRODUCTION

People living in the Balkans and Eastern Europe are typically breathing more toxic particulate air pollution than their neighbors in Western Europe, mostly due to wide use of coal-fired power plants, solid fuel heating and cooking (residential wood and coal stoves) and fewer air pollution reduction policies. Relative to European average level, cities in Bosnia and Herzegovina (consisted of Federation of Bosnia and Herzegovina, Republic of Srpska and Brčko District) have high ambient concentrations of health-damaging fine particulate air pollution [1].

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According to World Energy Council's definition of energy sustainability based on energy security, energy equity and environmental sustainability of energy systems, in 2021 Bosnia and Herzegovina ranked penultimate in Europe [2].

The primary energy supply of Bosnia and Herzegovina (B&H) is directed strongly towards fossil fuels [3]. In 2020, 70.5% of total generated electricity was produced using fossil fuels [4], [5]. B&H has large lignite reserves available at a reserve-to-production ratio of almost 200 years, thus most energy originates from coal (60%), followed by oil and gas [6].

The trend of using fossil fuels is the same in one of B&H entities, the Republic of Srpska (RS). In 2020, 72.3% of total generated electricity in RS was produced using fossil fuels [7]. Due to the prevalence of coal of satisfactory quality in the entire territory of the Republic of Srpska, it is the most represented energy resource used in RS [8].

Consequently, emissions intensity is high in RS and in entire B&H. The carbon intensity of B&H's total final energy consumption (TFEC) and of industrial consumption is almost double that of the EU (European Union) average. It is estimated that a significant emissions reduction will not occur soon, having in mind that the country's climate targets predict emissions increase until 2030 [6].

Due to predominant use of fossil fuels for energy production, air quality in Bosnia and Herzegovina is very low. According to [9] across the whole European continent $PM_{2.5}$ annual mean values in 2019 were the highest in Bosnia and Herzegovina.

More specifically, during the year 2020, air was excessively polluted in 2/3 of total agglomerations in the Republic of Srpska. The air was clean or slightly polluted in only one agglomeration (Trebinje). According to the data of the Republic Hydrometeorological Institute of the Republic of Srpska, in 2020 on the territory of Bijeljina the average annual limit values for NO_2, $PM_{2.5}$ and soot were exceeded. The limit values are determined according to the Decree on Air Quality Values (Official Gazette of the Republic of Srpska No. 124/12) [10].

The Paris Agreement is a document that in 2016 replaced the Kyoto Protocol, an earlier international agreement on restraining the release of greenhouse gases (GHG). Its main objective is to intensify the measures applied to combat climate change by holding the increase in the global average temperature to well below 2^{o}C above pre-industrial levels (Art. 2a, Paris Agreement). In order to achieve significant reduction of emissions, joint efforts are needed on a global scale, and that is why 195 countries from across the world signed the Paris Agreement [4].

Bosnia and Herzegovina is one of the signatories of the Paris Agreement. To meet the obligations under the Paris Agreement, the signatory parties were required to submit the Intended Nationally Determined Contributions (INDCs), with the respective targets, to mitigate climate change. In B&H main targets in the INDCs are:

- Unconditional reduction of GHG emissions by 2% below BAU ('business as usual') in 2030 (18% increase compared to 1990 level).
- Conditional reduction of 23% below BAU (3% below compared to 1990 level) is claimed in case of international support availability [4].

In order to meet the INDCs objectives, Bosnia and Herzegovina has to promote the use of clean energy that is not associated with GHG emissions, thus diversifying the energy mix. Besides environmental benefits of renewable energy (RE) use, it is also important for fulfillment of increasing power supply requirements [4], [7].

RS originally regulated the field of renewable energy sources by passing the Law on Electricity and the Law on Energy. These laws specifically prescribe the roles of the Government of the Republic of Srpska, i.e., the competent ministry and the Regulatory Commission in passing acts on promotion renewable energy sources. The adoption of the Law on Renewable Energy Sources and Efficient Cogeneration in May 2013 fully defined the legislative framework and enabled the functioning of the incentive system for all energy sources prescribed by law and thus created the conditions for unhindered implementation of obligations from the Treaty of establishing the Energy community regarding the fulfillment of the prescribed goals on the participation of energy from renewable sources in gross final energy consumption. The Law on Renewable Energy Sources and Efficient Cogeneration underwent certain amendments during 2013, as well as in 2015 and 2019 [7].

In May 2014, the Government of the Republic of Srpska adopted the Action Plan of the Republic of Srpska for the use of renewable energy sources. The Action Plan prescribes the planning of production and consumption of electricity produced in plants that use renewable energy sources. The Action Plan also defines the quantitative limits for the incentive electricity production. The quantities of electricity, depending on the type of renewable energy source, i.e., the applied technology, are given for each individual year until 2020. With the adoption of amendments to the Action Plan of the Republic of Srpska for the use of renewable energy sources on 03.12.2020 (Official Gazette of the Republic of Srpska, No. 124/20), the validity of the Action Plan was extended until 31.12.2021 [7].

The Republic of Srpska has a solid share of RES in the gross final consumption of electricity in relation to EU countries, mostly due to hydropower potential in the electricity segment. Therefore, further exploitation of renewable energy sources in the future will largely depend on price reduction of certain technologies, incentive mechanisms, and administrative barriers to obtaining licenses [11].

Climate change, GHG emissions, air quality and use of renewable energy sources (RES) are intertwining and overlapping. Increased RES use decreases use of fossil fuels thus automatically affects GHG emissions and improves air quality.

In RS, share of renewable energy sources in electricity production in 2020 was 27.6%, out of which 98.8% came from hydropower, leaving the potential of other RES underutilized [7].

Demand for electricity is growing because it is one of the main forms of energy used in the industrial and residential sectors, as well as in the commercial and public service sectors [4], [12], [13].

A favorable solution for meeting increasing needs for electricity is the use of photovoltaic (PV) technologies by which solar irradiation is directly converted into electricity [12], [14]. PV technologies use has many benefits such as clean [15] and free “fuel” and opportunity for countries to transform or develop their infrastructure and step up their low-carbon energy transition. Additionally, PV module prices have fallen 80% in the last decade, while installed capacity has grown from 40 GW to over 600 GW, according to the International Renewable Energy Agency (IRENA) [16], [17].

Due to many advantages and following energy laws and recommendations for increased use of renewable energy sources, according to IEA forecast [18], PV technology is going to become the largest installed electricity capacity in the world in 2027 (Fig. 1). Also, it is expected that renewables become the primary energy source for electricity in the world by the year 2026 [18].

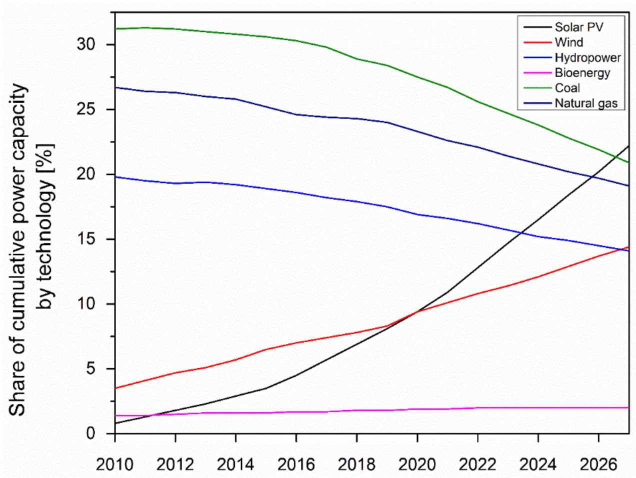

Fig. 1 Share of cumulative power capacity by technology in the period 2010-2027. Adapted from [19]

In March 2019, the parliament of Republic of Srpska adopted a new law on renewable energy and efficient cogeneration [20].

In RS, the incentive system is based on the most significant and most recognizable types of incentives: mandatory purchase of produced electricity at guaranteed purchase prices (feed-in tariffs (FiTs)) and a premium for consumption of produced electricity for own needs or selling on the RS market (feed-in premiums (FiPs)) [7], [20].

The right for incentive production of electricity from renewable sources and in efficient cogeneration, based on the contract on mandatory purchase of electricity at the end of 2020, was accomplished by 97 PV solar power plants, with a total installed power of 11.410 MW and planned annual production 14.063 GWh. In 2020, PV solar power plants generated 11.67 GWh of electricity, which is 83% of the planned annual production [7].

In 2020, 0.6% of generated renewable energy electricity and only 0.159% of total generated electricity in RS was produced using PV solar power plants [7].

There is limited data describing PV technologies use and the PV potential of the specific towns in RS. The aim of this paper is to give a detailed overview of the PV power potential in Bijeljina, in the Republic of Srpska in a global context. Firstly, an overview of solar irradiation values for the municipality of Bijeljina is given. Secondly, the energy of solar irradiation and also electrical energy which can be generated by the fixed, one-axis and dual-axis tracking PV solar power plants in the city of Bijeljina are reviewed. The area of Bijeljina is also considered regarding practical PV power potential and locations for possible PV systems installation. The main contribution of this paper is a critical evaluation of the available data from previous PV utilization studies [21], [22] in the light of recently created energy crisis, energy policies and available technology solutions for PV energy conversion. PV energy production contribution is analyzed per month, based on real climate data for a given location. The possibility of larger scale solar energy utilization was analyzed, depending on seasonal consumption and production in the city of Bijeljina. The intention of this paper is to raise the share of electricity produced using PV technologies in total generated electricity in RS by contributing to PV potential data for Bijeljina (that are often not publicly available in the English language).

2. Geographical Location of Bijeljina and Electricity Consumption

Bijeljina (Fig. 2) is a city and the center of the municipality of the same name. It is located in the northeastern part of the Republic of Srpska at coordinates 44.758° north and 19.211° east, 90 m above sea level. The area of the municipality of Bijeljina is 734 km^2, and the total population is about 105000. On the 2013 census, the city of Bijeljina had 41121 inhabitants according to the data of the Republic of Srpska Institute of Statistics, and 42278 inhabitants according to the data of the Agency for Statistics of Bosnia and Herzegovina. Bijeljina is the second largest settlement in the RS after Banja Luka. Bijeljina is located in the plain of Semberija and is a crossroads for Serbia, Croatia and the interior of Bosnia and Herzegovina. Since it is located practically in the center of the fertile plain, it is one of the centers of food production and trade. The majority of production consists of wheat and corn cereals and vegetables such as cabbage, peppers and tomatoes. Fruit growing and animal husbandry are also represented, but to a lesser extent [22], [23].

Fig. 2 The geographical location of Bijeljina in Bosnia and Herzegovina [23]

The City Administration of Bijeljina has advanced furthest in the localization process of Agenda 2030 into everyday work and strategic planning at the local level. Agenda 2030 is the most comprehensive global sustainable and transformational development agreement for all United Nations Member States and has the Sustainable Development Goals (SDG) at its core. The City of Bijeljina is the first city/municipality in the Republic of Srpska (also in Bosnia and Herzegovina) to adjust and include relevant SDG targets and indicators into its development strategy. In 2018 SDGs were included into the revised Development Strategy of the City of Bijeljina for the period 2019-2023 [24].

The Subsidiary Electricity Distribution Company (Zavisno elektrodistributivno preduzeće (ZEDP)) "Elektro-Bijeljina" A.D. Bijeljina, which deals with the distribution and production of electricity, is in charge of supplying Bijeljina with electricity. It consists of five field units, two of which (mostly the Bijeljina field unit and to a lesser extent Ugljevik field unit) cover the territory of the city of Bijeljina [25].

Bijeljina is very important part of the electricity distribution system of the Republic of Srpska, as well as the whole of Bosnia and Herzegovina, especially because of its border position (it is located on the border with Serbia).

In 2020, ZEDP "Elektro-Bijeljina" A.D. participated with 513.26 GWh (or 12%) in the balance of total electricity consumption (supply of electricity to end users) in Mixed Holding Power Utility of Republic of Srpska (MH "Elektroprivreda Republike Srpske") [26].

In the period 2012-2021, most of electricity consumption in ZEDP "Elektro-Bijeljina" A.D. was used in households (55-60%). Low voltage electricity consumption in households, public lighting and other consumption accounted for 71.3% (2020) and 70.7% (2021) in total electricity consumption in ZEDP "Elektro-Bijeljina" A.D. [27].

In 2015, the City of Bijeljina announced a public call for the lease of rooftops of public buildings for the PV systems installation, total power of 800 kW [28]. The first PV solar power plant in Bijeljina power of 180 kWp was installed in 2015, on the sports hall roof of one primary school [28], [29].

According to the ZEDP "Elektro-Bijeljina" A.D. report for 2020, the procured electricity from PV solar power plants in the Bijeljina field unit amounted to 116.374 MWh of electricity, and the total from all field units within the ZEDP "Elektro-Bijeljina" A.D. amounted to 363.494 MWh of electricity [25].

3. Estimation of Solar Irradiation in Bijeljina

The optimal use of PV systems requires accurate estimates of solar photovoltaic potential. Geographic information systems (GISs)-based estimation is a promising approach for estimating solar photovoltaic potential [30], [31].

In order to estimate PV potential of Bijeljina, PVGIS and SOLARGIS databases were used.

PVGIS (Photovoltaic Geographical Information System) is very important for PV implementation because it estimates dynamics of the correlations between solar irradiation, climate, atmosphere, the earth's surface and the PV technology used [32], [33]. PVGIS has been developed at the European Commission Joint Research Centre (JRC) in Ispra, Italy [34].

Global Solar Atlas provides quick and easy access to solar resources and photovoltaic power potential data globally. It has been prepared by Solargis under a contract to The World Bank, based on a solar resource database that they own and maintain. It is funded by the Energy Sector Management Assistance Program (ESMAP), a multi-donor trust fund administered by The World Bank and supported by 13 official bilateral donors. The World Bank Group has selected Solargis as its global provider of solar data and related solar energy assessment services [35].

In the municipality of Bijeljina global horizontal irradiation has values in the range 3.64 – 3.68 kWh/m^2 (per day) (Fig. 3(a)), direct normal irradiation in the range 3.31 – 3.36 kWh/m^2 (per day) (Fig. 3(b)), and diffuse horizontal irradiation in the range 1.70 – 1.71 kWh/m^2 (per day) (Fig. 3(c)).

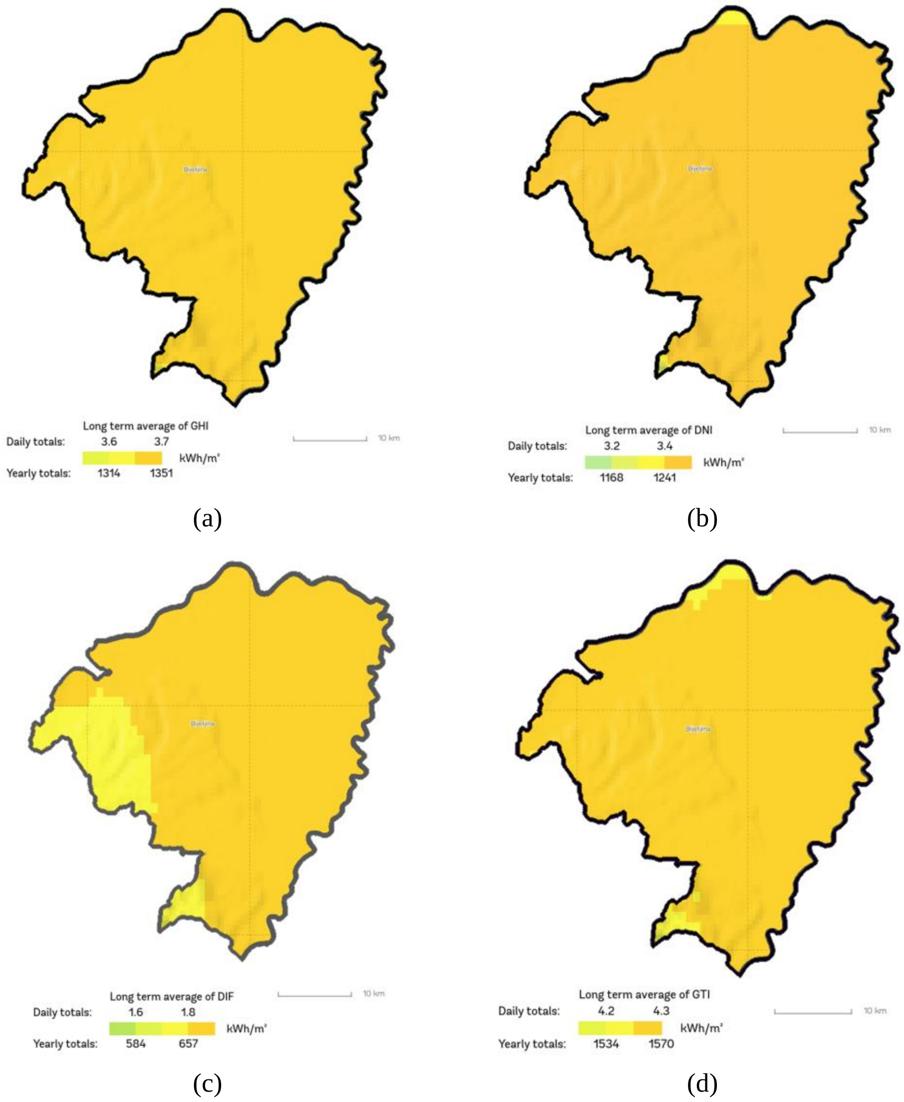

Fig. 3 Global horizontal irradiation (a), Direct normal irradiation (b), Diffuse horizontal irradiation (c) and Global tilted irradiation (d) in the municipality of Bijeljina. Adapted from [35]

In the municipality of Bijeljina optimal PV module angle (tilt angle) is in the range 34-35^{o}, and global tilted irradiation has values in the range 4.21 – 4.26 kWh/m^2 (per day) (Fig. 3(d)).

In Bijeljina, the average insolation is 1800-1900 hours per year, which is 4.9-5.2 hours a day. The insolation is highest in summer and lowest in winter [21].

According to PVGIS, optimal PV module tilt angle in Bijeljina is 34°. Energy of the solar irradiation falling on the horizontal, optimally tilted and vertically placed surface in the city of Bijeljina per year are given in Table 1.

Table 1 Energy of the solar irradiation falling on the horizontal, optimally tilted and vertically placed surface in Bijeljina per year [36]

Location	Energy of solar irradiation falling		
	on the horizontal surface (Wh/m^2)	on the optimally tilted surface (Wh/m^2)	on the vertically placed surface (Wh/m^2)
Bijeljina	3315.83	3777.55	2534.73

Based on the data shown in Table 1 it can be seen that in Bijeljina the largest amount of solar irradiation energy falls on the optimally placed surface, slightly less on the horizontal, and the lowest on the vertically placed surface. The horizontal surface receives 12.22%, and the vertical 32.90% less energy of solar irradiation in relation to the optimally placed surface.

Although it is well known that the largest amount of solar irradiation falls on the optimally placed surface, it is important to calculate amount on the vertically and horizontally placed surface for BIPV (Building Integrated Photovoltaics) application because PV systems can be easily integrated with the existing and new building structures (rooftops and façades) [30], [37], [38], [39].

4. Estimation of PV Output Potential in Bijeljina

The practical PV potential of some locations is illustrated by the estimated power output produced per unit capacity of the assumed PV system configuration - the PVOUT (Photovoltaic Power Output (Potential)) variable, measured in kWh/kWp. No PV technology can exploit the full theoretical potential of the solar resource determined by global horizontal irradiation (GHI) (and direct normal irradiation (DNI) as complementary information). Besides GHI (and DNI), leading natural factor influencing PV power production is the air temperature because the PV conversion efficiency decreases at higher temperatures. Locations where solar irradiation has values below the average may benefit from lower air temperatures during the year, and inversely, higher air temperatures may hinder the PV power output at locations with high solar irradiation values. The practical PV power potential is also limited by various physical and regulatory land-use constraints, the configuration of the PV system, the conversion efficiency of PV modules, and the shading and soiling of the modules [16].

For specific locations the estimated solar photovoltaic power generation potential can be found using specialized software [40]. Countries in the Middle East and North Africa region and Sub-Saharan Africa have excellent conditions for PV utilization, where long-term daily PVOUT averages exceed 4.5 kWh/kWp [16]. Countries with the favorable mid-range PVOUT values between 3.5 and 4.5 kWh/kWp account for 71% of the global population (including five of the six most populous countries (China, India, the United States, Indonesia, and Brazil) and 100 others (Canada, the rest of Latin America, southern Europe, African countries around the Gulf of Guinea, and central and southeast Asia)) [16].

Around 9% of the global population lives in 30 countries with average PVOUT below 3.5 kWh/kWp, dominated by European countries – except those in southern Europe. Even in countries with lower PVOUT values, the practical PV power potential is not significantly lower compared to the top-performing countries [16]. RS, and Bijeljina as part of southeastern Europe are located in the western part of the Balkan peninsula. The average solar irradiation in the Balkan countries is about 40% higher than the European average, but despite that, the use of solar energy is at a much lower level than in the European Union countries [16], [22]. In Bosnia and Herzegovina, PVOUT is in the range 3.22 – 4.10 kWh/kWp, while the average PVOUT is 3.57 kWh/kWp. According to the average practical PV potential, B&H is in the 174th place in the world [35].

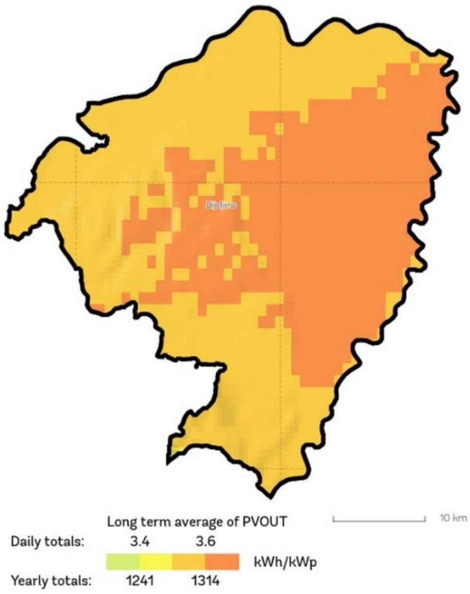

Fig. 4 Photovoltaic power potential for the municipality of Bijeljina. Adapted from [35]

Fig. 4. shows that in the municipality of Bijeljina PVOUT has values in the range 3.47 – 3.51 kWh/kWp (per day). Average value of PVOUT in Bijeljina municipality is 3.50 kWh/kWp. Only 10% of its territory has PVOUT less or equal 3.48 kWh/kWp, 50% PVOUT less or equal 3.50 kWh/kWp, and 90% of the Bijeljina municipality has PVOUT less or equal 3.51 kWh/kWp.

Using PVGIS program, calculated amount of electricity that can be generated with ground-mounted fixed, one-axis and dual-axis tracking PV solar power plants with monocrystalline silicon PV modules in Bijeljina are given in Table 2.

Table 2 PVGIS characteristics of a fixed, one-axis and dual-axis tracking PV solar power plant power of 1 MWp that would be installed in Bijeljina [36]

	Fixed	One-axis tracking	Dual-axis tracking
Power of photovoltaic solar power plant (MWp)	1	1	1
Power plant losses (%)	14	14	14
Tilt angle (°)	34	36	
Annual electricity production (kWh)	1180536.78	1527103.13	1562084.74

Based on the data shown in Table 2, it can be seen that one-axis tracking PV solar power plant generates 29.36% more electricity in relation to a fixed PV solar power plant. The dual-axis tracking PV solar power plant generates 32.32% more electricity as compared to a fixed PV solar power plant. PV solar power plant installation is very complex because it should consider not only electricity production, but also initial investment, maintenance and operation cost, technical solution fitting in the environment, etc.

The economic potential describes how much it costs to produce a unit of energy compared to other energy generation sources. PV economic potential in most countries in the world varies between $0.06/kWh and $0.14/kWh, and over 75% of the evaluated global area scores below $0.12/kWh [16]. In B&H, average LCOE (levelized cost of electricity) is $0.12/kWh, thus making PV technologies competitive with conventional power-generating sources [35].

Sensitivity analysis for the LCOE of a PV system shows a strong dependance on solar irradiation and investment cost [41]. [42] investigated the sensitivity of energy rating of PV modules to different factors (including an uncertainty model). A sensitivity analysis discovered the measurement of irradiance and the nominal PV module operating temperature as the most significant sources of uncertainty [42].

The Paris Agreement has also recognized the global role of cities and authorities in achieving reductions in carbon emissions, thus the integration of PV technologies has been recommended (or made mandatory) in new EU buildings [30]. With the availability of existing building structures there is no need for additional land for PV systems installation [43]. Exploiting rooftops of public buildings for PV systems installation is also an opportunity for improvement of buildings energy efficiency and mitigate carbon emissions [30], [44], [45]. There are also several challenges for roof-mounted PV system utilization in urban environments, such as soiling, shading, etc. Soiling can reduce power output of PV systems especially in countries with energy system significantly relied on fossil fuels utilization [12], [46], [47]. Although it is not easy to accurately estimate the rooftop PV potential of a city, it is important especially for policymaking [48], [49]. Due to urban environment and space limitation in the city of Bijeljina, several solutions for PV systems installation on existing rooftops of public buildings were considered, taking into account favorable rooftop orientation without high initial investment for reconstruction.

5. Case Studies of Practical PV Power Potential of Bijeljina

In this part, the findings of previous studies for 1 MWp ground-mounted PV system and three roof-mounted PV systems are shown in the light of PV technologies development as the key factor for broader use in the future. Afterwards, electricity production from PV systems in one year period is considered, with special reference to uneven production characteristic for cities in continental climate, like Bijeljina.

5.1. Analysis of previous PV installations studies

In [21] an analysis of suitable rooftop and ground areas for PV systems installation in the area of Bijeljina was performed. Using satellite images, the analysis showed potential for roof-mounted photovoltaic systems. In this case, the total installed power would be 4 MWp which means 8500 MWh of electricity production annually. This amount could cover the complete electricity demand for municipal services such as street lighting, electric heating in public buildings etc., and about 5% of the total electricity demand. Besides the installation of rooftop PV systems, there is also the possibility for the installation of ground-mounted PV systems. In this case a PV system with a power of 1 MWp requires an area of around 3 ha. For fulfillment of electricity demand of Bijeljina municipality for public services, it would be enough to install ground-mounted PV system power of 2.5 MWp [21].

In [22], a selection of public buildings for PV systems installation on the territory of Bijeljina municipality was performed. In order to get high values of solar energy and at the same time avoid excessive and irrational costs, attention was primarily paid to public buildings orientation, the shadows of surrounding objects and infrastructural conditions for installing PV systems. According to all above mentioned conditions, three public buildings were selected for the installation of PV modules on their roofs and façade. For the first object, designated as Building 1, with roof area of 1605 m^2, installation of 360 PV modules ideally south oriented was planned, and also installation of 72 PV modules on the south façade. With polycrystalline PV modules available in 2014 (Table 4), predicted installation power was 103.68 kWp and estimated annual average electricity production was 119380 kWh. In a similar way, for the second object designated as Building 2 with ideally south oriented roof area of 2156 m^2, installation of 332 optimally inclined (34^o) PV modules was planned. With the installation of PV system power of 79.68 kWp, annual average electricity production would be 91700 kWh. The third object, designated as Building 3, with roof area of 1350 m^2 enables installation of 179 PV modules total power of 42.96 kWp with annual average electricity production of 49400 kWh. Due to constructional limitations, PV modules couldn't be south oriented – 124 PV modules would be with southwest orientation, and 55 PV modules with southeast orientation. It was estimated that by using these three PV systems on Building 1, Building 2, and Building 3, annual reduction of CO_2 emission in Bijeljina municipality would be 268943.4 kg [22]. So far, none of these PV systems has been installed on any of the three public buildings.

5.2. State-of-the-art PV installations analysis and future perspective

PV technologies have experienced considerable development progress and price acceptability during the last decade. From relatively short time interval (8 years), this paper gives a comparison with findings of previous PV system installation feasibility studies for Bijeljina [21], [22] and also gives a recommendation for redesign of previous and current technical solutions with the utilization of the latest PV technologies.

As mentioned in previous chapter, none of PV systems planned for Building 1, Building 2 and Building 3 hasn't been realized, mostly due to relatively low electricity price in Bosnia and Herzegovina in the period 2014-2020, as shown in Table 3 [50].

Quite slow and late adoption of incentive measures for PV electricity production contributed to economic unattractiveness and practical unfeasibility of three above mentioned PV systems [7]. During 2022 electricity price increase became considerable, improving commercial perspectives of PV installations. Additionally, further decrease of electricity generated from photovoltaics makes them more attractive [41]. Also, policy makers demand reduction of fossil fuel energy production and consumption, and consequently renewable energy utilization growth [4], [7]. For RS and Bijeljina area, PV energy imposes itself as favorable solution.

Table 3 Electricity price for household and non-household consumers in Bosnia and Herzegovina [50]

	Electricity price for household consumers (EUR/kWh)	Electricity price for non-household consumers (EUR/kWh)
2014	0.0676	0.0652
2015	0.0694	0.0625
2016	0.0711	0.0612
2017	0.0720	0.0581
2018	0.0722	0.0643
2019	0.0729	0.0647
2020	0.0721	0.0708
2021	0.0721	0.0719
2022	0.0733	0.0714

Hereinafter, according to real typical meteorological year data, results of detailed analysis of electricity production from PV system at Building 1, Building 2, and Building 3 are going to be shown. For this purpose, PVSYST 7.3.1 software (demo version) with included meteorological data was used [51]. Also, compared to previous studies [21], [22], modern recently developed and commercially available PV modules are used (Table 4).

Table 4 Basic data of two generation of PV modules [22], [51]

	PV modules (2014)	PV modules (2022)
Type	polycrystalline	monocrystalline
Maximum Power (W)	240	300
Efficiency at STC (%)	14.89	20.56
No. of cells	60	60
Dimension W x L (mm)	1639 x 983	1640 x 992

Figures 5-7. comparatively show monthly values of electricity impressed into electrical grid (E_{grid}) for Building 1, Building 2, and Building 3. First of all, considerable seasonality of electricity production can be noticed. As expected, the highest electricity production is in the period between April and October, with the maximum values in July. Minimal electricity generation is in January and represents around 50% of calculated December production. Having in mind that fixed PV solar power plants generates the highest electricity values during summer and that the highest electricity demand occurs during winter months (with corresponding air pollution highest values), getting the greatest electricity values when they are most needed is debatable.

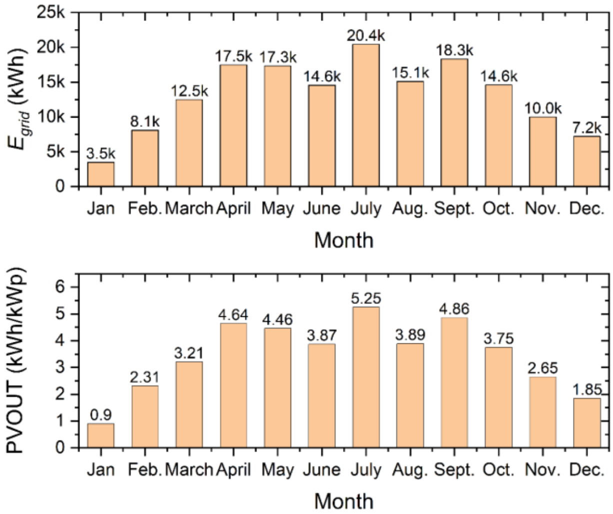

Fig. 5 Monthly distribution of produced electricity and PVOUT for Building 1 [51]

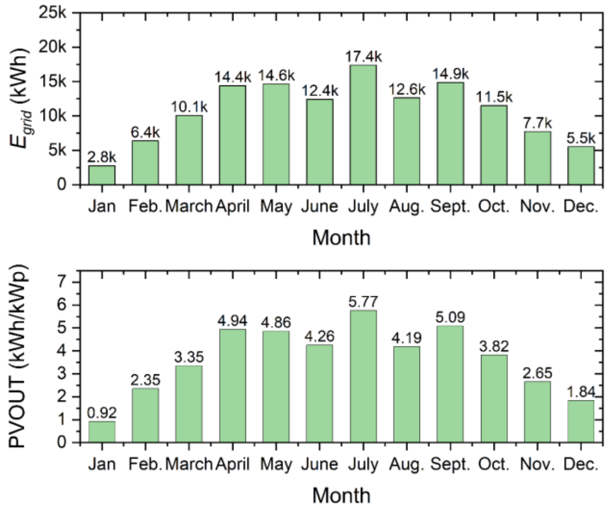

Fig. 6 Monthly distribution of produced electricity and PVOUT for Building 2 [51]

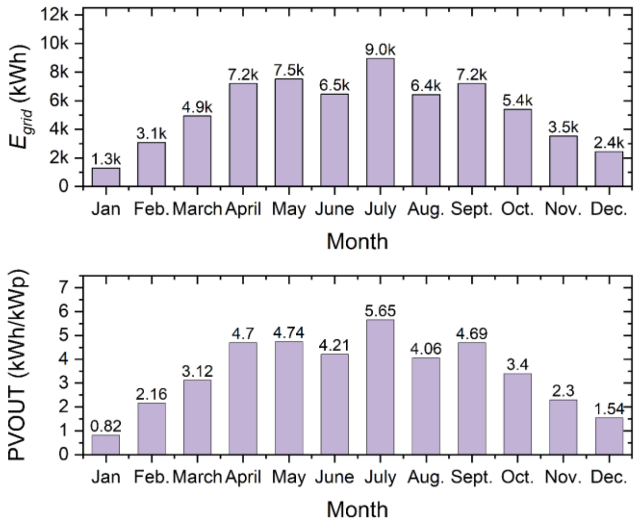

Fig. 7 Monthly distribution of produced electricity and PVOUT for Building 3 [51]

PVOUT (Normalized Performance Coefficient in PVSYST) average annual values for Building 1, Building 2, and Building 3 are 3.47, 3.67, and 3.45, respectively. Different PVOUT values are consequence of way of PV modules installation, orientation, etc. Building 2 with all PV modules optimally inclined and south oriented has the highest PVOUT value. For the sake of comparison, 72 PV modules on Building 1 are vertically inclined, and on Building 3, PV modules have southwest and southeast orientation.

Table 5 gives comparison of the main parameters from previous study [22] and PVSYST simulation for Building 1, Building 2, and Building 3. Increasement in produced electricity can be noticed, mostly due to utilization of new generation PV modules, better optimization of PV modules in strings, and utilization of new generation inverters with average efficiency of 96%. As a result, total electricity generation in Building 1 increased for 33.2%, in Building 2 for 42%, and in Building 3 for 30.4%. It can be concluded that PV modules orientation is of very high importance for roof-mounted PV installations in order to get maximum electricity production from new generation PV modules.

Table 5 Comparison of the main parameters from previous study [22] and PVSYST simulation (2022) for public objects (Building 1, Building 2, and Building 3)

Name of PV system		Number of PV modules	Installed power (kWp)	Produced energy (kWh/year)
Building 1	Previous	432	103.68	119380
	New concept	429	129	159046
Building 2	Previous	332	79.68	91700
	New concept	330	99	130226
Building 3	Previous	179	42.96	49400
	New concept	174	52	64398

According to publicly available data [25], electricity consumption seasonality for each month in the period 2018-2021 in Bijeljina was analyzed (Fig. 8). Obtained monthly electricity consumption results are presented in relative percentage units, compared to the total electricity consumption for each year.

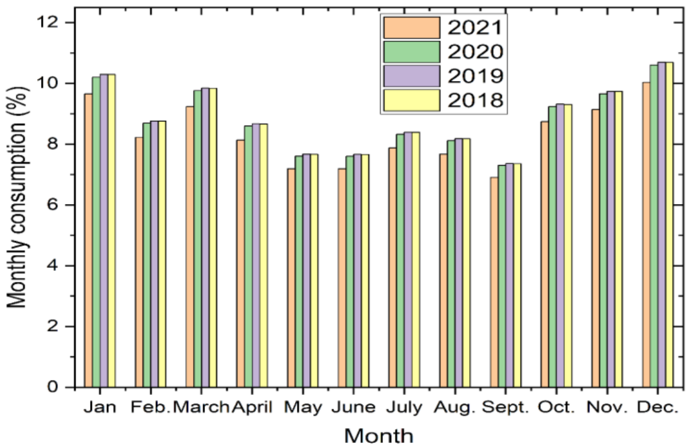

Fig. 8 Electricity consumption data for each month in the period 2018-2021 in Bijeljina [25]

It can be observed that electricity consumption during summer months is 2-3% lower compared to winter months. Electricity consumption in February is ostensibly lower due to the lesser number of days.

Seasonality issue for photovoltaic electricity generation is additionally analyzed for ground-mounted PV plant power of 1 MWp in Bijeljina, based on PVSYST simulation. Figure 9. compares monthly electricity production in Bijeljina for fixed, one-axis and dual-axis tracking PV solar power plants (like in Table 2).

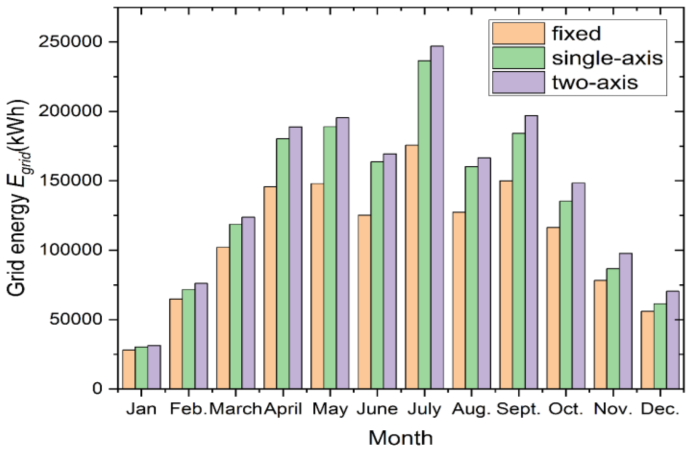

Fig. 9 Monthly electricity production from fixed, one-axis and dual-axis tracking PV solar power plants power of 1 MWp in Bijeljina [51]

It can be noted that tracking PV solar power plants utilization increases electricity production during summer months, especially in July (34% for one-axis, and 40.6% for dual-axis). Electricity production growth during winter months is relatively low. Namely, one-axis tracking PV solar power plant utilization increases electricity production by 8-10% compared to fixed PV solar power plant during November, December, January and February, and for 16% in March. Dual-axis tracking PV solar plant utilization increases electricity production for around 25% in November and December, 12% in January, 17% in February and around 21% in March.

According to conducted simulations and obtained results, it can be concluded that:

- increase of PV modules and grid inverters efficiency leads to considerable electricity production growth;
- maximum exploitation of solar energy largely depends on optimal PV modules installation;
- PV electricity production seasonality issue in Bijeljina and neighboring areas is significant and cannot be improved even by PV tracking systems utilization – electricity production growth is highest during summer months with already high production (and lower electricity consumption).

6. Conclusions

In the Republic of Srpska electricity is still mostly generated by using fossil fuels. As a consequence, during the year 2020, air was excessively polluted in 2/3 of total agglomerations in the Republic of Srpska. A favorable solution for decreasing fossil fuel electricity production and thus improving air quality is the use of PV technologies. The top benefits of PV technologies are production of clean energy without greenhouse gasses emissions, sustainability, scalability, versatility, installation price reduction and short project construction time.

This paper gives an overview of the PV power potential in Bijeljina, Republic of Srpska. In the light of all said, it can be concluded that in the municipality of Bijeljina global horizontal irradiation has values in the range 3.64 – 3.68 kWh/m^2 (per day), direct normal irradiation in the range 3.31 – 3.36 kWh/m^2 (per day), and diffuse horizontal irradiation in the range 1.70 – 1.71 kWh/m^2 (per day). Optimal PV module angle is in the range 34-35^o, and global tilted irradiation has values in the range 4.21 – 4.26 kWh/m^2 (per day).

For the city of Bijeljina, it can be concluded that 12.22% less energy of solar irradiation falls on the horizontally placed surface, and 32.90% less on the vertically placed surface in relation to the optimally placed surface, and that the one-axis tracking solar power plant generates 29.36% more electricity and the dual-axis tracking PV solar power plant generates 32.32% more electricity as compared to a fixed PV solar power plant.

Average value of PVOUT in Bijeljina municipality is 3.50 kWh/kWp and thus belongs to areas with the favorable mid-range values between 3.5 and 4.5 kWh/kWp. Average LCOE is $0.12/kWh, consequently making PV technologies in Bijeljina and RS also economically competitive with conventional power-generating sources. It can be concluded that Bijeljina has good practical and economical PV potential, and also legislative basis for wider use of PV systems.

On the territory of Bijeljina municipality, three public buildings were selected for the installation of PV modules on their roofs and façade. After only eight years from initial feasibility study, analysis of possibility of PV solar power plants installation on the rooftops of three public buildings in Bijeljina was conducted, with identical installation conditions, but with new generation PV modules and inverters. It was concluded that technological improvement of PV solar power plants components has favorable influence on PV electricity production (30.4-42%). This innovated study and redesign showed that for the considerable PV electricity production growth, PV modules installation should be very close to ideal.

The results obtained in this paper are important for the increasing share of electricity generated using PV technologies in Bijeljina and RS as well, for reducing the load on the existing electricity sources and for improving air quality. The presented results and methodology can be used to plan and design PV solar power plants and systems in private households and other facilities. They should assist the stakeholders in the identification of POAs (project opportunity areas) in Bijeljina municipality as a follow-up action. Also, they should initiate raising awareness of PV benefits and wider use of PV systems in Bijeljina.

With the adoption of the Law on Renewable Energy Sources and Efficient Cogeneration, a legal framework in the Republic of Srpska has been created for the final definition of the system for the incentive production of electricity from renewable energy sources and efficient cogeneration. The government of the Republic of Srpska has also adopted the Action Plan that prescribes the planning of production and consumption of electricity from renewable energy sources. Since its first publication, the Action Plan, in the part related to the quantitative limits for the incentive electricity, has undergone changes in quantities depending on the source, but the total planned amount of electricity produced from renewable sources (until 2021) remained unchanged.

It can be concluded that promoting the production and consumption of electricity from renewable energy sources is in the interest of security supplying, preserving the environment and preventing climate change, ensuring constant and a reasonable increase in the share of energy from renewable sources in total energy consumption, enabling economic use of natural sources, and in the interest of sustainable development of local self-government units and social cohesion.

In RS further exploitation of renewable energy sources in the future will largely depend on price reduction of certain technologies, incentive mechanisms, and administrative barriers. Although the Republic of Srpska has a good position from the renewable energy resources perspective, as part of further strategic planning, additional activities need to be done to update data on the potential for their further exploitation.

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REFERENCES

[1] Report No: AUS0001227, *Air pollution management in Bosnia and Herzegovina*. Western Balkans, Regional AQM – Western Balkans, Report – AQM in Bosnia and Herzegovina, World Bank, 2019.

[2] World Energy Council in partnership with Oliver Wyman, *World Energy Trilemma Index 2021*.

[3] T. Pavlović, D. Milosavljević, D. Mirjanić, L. Pantić, I. Radonjić and D. Piršl, "Assessments and perspectives of PV solar power engineering in the Republic of Srpska (Bosnia and Herzegovina)", *Renew. Sust. Energy Rev.*, vol.18, pp.119-133, 2013.

[4] M. P. Pablo-Romero, A. Sanchez-Braza and A. Galyan, "Renewable energy use for electricity generation in transition economies: Evolution, targets and promotion policies", *Renew. Sust. Energy Rev.*, vol. 138, p. 110481, 2021.

[5] *International Energy Agency data*. Available at: https://www.iea.org/countries/bosnia-and-herzegovina

[6] L. Eicke, S. Weko, M. Apergi and A. Marian, "Pulling up the carbon ladder? Decarbonization, dependence, and third-country risks from the European carbon border adjustment mechanism", *Energy Res. Soc. Sci.*, vol. 80, p. 102240, 2021.

[7] *Regulatory report about the electricity market, natural gas, oil and oil derivatives in the Republic of Srpska for 2020* (in Serbian), 2021. Available at: https://reers.ba/wp-content/uploads/2021/07/Izvjestaj_RERS_2020_LAT_2_dio.pdf

[8] *Thermal energy potential data* (in Serbian). Available at: https://ers.ba/termoenergetski-potencijal/

[9] *2019 World Air Quality Report, Region & City PM2.5 Ranking*. IQAir, 2020.

[10] *Annual report on air quality in the Republic of Srpska for 2020*. 2020. Available at: https://rhmzrs.com/report/godisnji-izvjestaj-o-kvalitetu-vazduha-u-republici-srpskoj-za-2020-godinu/

[11] Government of the Republic of Srpska, *Energy Development Strategy of the Republic of Srpska until 2035*. Banja Luka: 2018. (Vlada Republike Srpske, *Strategija razvoja energetike Republike Srpske do 2035. godine*. Banja Luka: 2018.).

[12] I. Radonjić, T. Pavlović, D. Mirjanić and L. Pantić, "Investigation of fly ash soiling effectes on solar modules performances", *Sol. Energy*, vol. 220, pp. 144-151, 2021.

[13] L. R. Rodríguez, E. Duminil, J. S. Ramos and U. Eicker, "Assessment of the photovoltaic potential at urban level based on 3D city models: A case study and new methodological approach", *Sol. Energy*, vol. 146, pp. 264-275, 2017.

[14] H. Abuzaid, L. A. Moeilak and A. Alzaatreh, "Customers' perception of residential photovoltaic solar projects in the UAE: A structural equation modeling approach", *Energy Strateg. Rev.*, vol. 39, p. 100778, 2022.

[15] M. Krstic, L. Pantic, S. Djordjevic, I. Radonjic, V. Begovic, B. Radovanovic and M. Mancic, "Passive cooling of photovoltaic panel by aluminum heat sinks and numerical simulation", *Ain. Shams. Eng. J.*, in press.

[16] *Global Photovoltaic Power Potential by Country*. ESMAP, The World Bank, IBRD-IDA, World Bank Group, 2020, http://documents1.worldbank.org/curated/en/466331592817725242/pdf/Global-Photovoltaic-Power-Potential-by-Country.pdf

[17] E. Fuster-Palop, C. Prades-Gil, X. Masip, J. D. Viana-Fons and J. Payá, "Innovative regression-based methodology to assess the techno-economic performance of photovoltaic installations in urban areas", *Renew. Sust. Energy Rev.*, vol. 149, p. 111357, 2021.

[18] International Energy Agency, *Renewables 2022, Analysis and forecast to 2027*. Available at: https://iea.blob.core.windows.net/assets/64c27e00-c6cb-48f1-a8f0-082054e3ece6/Renewables2022.pdf

[19] International Energy Agency, Share of cumulative power capacity by technology. Available at: https://www.iea.org/data-and-statistics/charts/share-of-cumulative-power-capacity-by-technology-2010-2027

[20] IRENA, *Renewable Energy Market Analysis: Southeast Europe*. Abu Dhabi: 2019, ISBN 978-92-9260-166-9.

[21] Energy Development Plan, Cross border development, *Bijeljina & Bogatić: cross border development*. 17.02.2014. Available at: https://www.investinbijeljina.org/download/20140210_energy_development_plan_final_version.pdf

[22] M. Petrović, et al., *Feasibility Study for use of Solar Energy for obtaining Thermal and Electric Energy in the town of Bijeljina and Municipality of Bogatic*. Sarajevo: Enova, 2014. Available at: http://www.bogatic.rs/ler/cms/download/studija-solarna-energija-1.pdf

[23] Details about the city of Bijeljina. Available at: https://sr.wikipedia.org/sr-el/Бијељина

[24] Sustainable Development Goals, *VOLUNTARY REVIEW, Implementation of Agenda 2030 and the Sustainable Development Goals in Bosnia and Herzegovina*. 2019. Available at: https://sustainabledevelopment.un.org/content/documents/23345VNR_BiH_ENG_Final.pdf

[25] Electro distribution company details. Available at: https://www.elektrobijeljina.com/

[26] Government of the Republic of Srpska, *Electricity balance of the Republic of Srpska for 2020*. Banja Luka: 2020. (Vlada Republike Srpske, *Elektroenergetski bilans Republike Srpske za 2020. godinu*. Banja Luka: 2020.).

[27] ZEDP "Elektro-Bijeljina" A.D., *Report on technical affairs for the period I-XII 2021*. Bijeljina: 2022. (ZEDP "Elektro-Bijeljina" A.D., *Izvještaj o tehničkim poslovima za period I-XII 2021. god.* Bijeljina: 2022).

[28] Public call for solar plants. Available at: https://gradbijeljina.org/lat/news/novosti//892.raspisan-javni-poziv-za-solarne-elektrane.html
[29] D. D. Milosavljević, T. M. Pavlović, D. Lj. Mirjanić and D. Divnić, "Photovoltaic solar plants in the Republic of Srpska – current state and perspectives", *Renew. Sust. Energy Rev*, vol. 62, pp. 546-560, 2016.
[30] A. A. A. Gassar and S. H. Cha, "Review of geographic information systems-based rooftop solar photovoltaic potential estimation approaches at urban scales", *Appl. Energy*, vol. 291, 116817, 2021.
[31] K. Bódis, I. Kougias, A. Jäger-Waldau, N. Taylor and S. Szabó, "A high-resolution geospatial assessment of the rooftop solar photovoltaic potential in the European Union", *Renew. Sust. Energ. Rev.*, vol. 114, p. 109309, 2019.
[32] T. Pavlović ed., T. Pavlovic, A. Tsangrassoulis, N. Dj. Cekic, P. Ts. Tsankov, D. Lj. Mirjanic and I. S. Radonjic Mitic, *The Sun and Photovoltaic Technologies.* Springer, 2020, ISBN 978-3-030-22403-5.
[33] T. Pavlović, I. Radonjić, D. Milosavljević, L. Pantić and D. Piršl, "Assessment and potential use of concentrating solar power plants in Serbia and Republic of Srpska", *Therm. Sci.*, vol. 16, no. 3, pp. 931-945, 2012.
[34] Photovoltaic Geographical Information System. Data available at: https://ec.europa.eu/jrc/en/pvgis
[35] Global Solar Atlas. Available at: https://globalsolaratlas.info/map
[36] Photovoltaic Geographical Information System. Data available at: https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html
[37] A. Boccalatte, M. Fossa and C. Ménézo, "Best arrangement of BIPV surfaces for future NZEB districts while considering urban heat island effects and the reduction of reflected radiation from solar façades", *Renew. Energy*, vol. 160, pp. 686-697, 2020.
[38] J. Polo, N. Martín-Chivelet, M. Alonso-Abella and C. Alonso-García, "Photovoltaic generation on vertical façades in urban context from open satellite-derived solar resource data", *Sol. Energy*, vol. 224, pp. 1396-1405, 2021.
[39] H. Sun, C. K. Heng, S. E. R. Tay, T. Chen and T. Reindl, "Comprehensive feasibility assessment of building integrated photovoltaics (BIPV) on building surfaces in high-density urban environments", *Sol. Energy*, vol. 225, pp. 734-746, 2021.
[40] Solar data behind the maps. Data available at: https://solargis.com/maps-and-gis-data/tech-specs
[41] Fraunhofer ISE, *Levelized cost of electricity renewable energy technologies.* 2021. Available at: https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/EN2021_Fraunhofer-ISE_LCOE_Renewable_Energy_Technologies.pdf
[42] J. C. Blakesley, T. Huld, H. Müllejans, A. Gracia-Amillo, G. Friesen, T. R. Betts and W. Hermann, "Accuracy, cost and sensitivity analysis of PV energy rating", *Sol. Energy*, vol. 203, pp. 91-100, 2020.
[43] J. Allegrini, K. Orehounig, G. Mavromatidis, F. Ruesch, V. Dorer and R. Evins, "A review of modelling approaches and tools for the simulation of district-scale energy systems", *Renew. Sust. Energy Rev.*, vol. 52, pp. 1391-1404, 2015.
[44] K. Mainzer, S. Killinger, R. McKenna and W. Fichtner, "Assessment of rooftop photovoltaic potentials at the urban level using publicly available geodata and image recognition techniques", *Sol. Energy*, vol. 155, pp. 561-573, 2017.
[45] L. S. Pantić, T. M. Pavlović, D. D. Milosavljević, D. Lj. Mirjanić, I. S. Radonjić and M. K. Radović, "Electrical energy generation with differently oriented PV modules as façade elements", *Therm. Sci.*, vol. 20, no. 4, pp. 1377-1386, 2016.
[46] M. P. Petronijevic, I. Radonjic, M. Dimitrijevic, L. Pantic and M. Calasan, "Performance evaluation of single-stage photovoltaic inverters under soiling conditions", *Ain. Shams. Eng. J.*, in press.
[47] I. S. Radonjić, T. M. Pavlović, D. Lj. Mirjanić, M. K. Radović, D. D. Milosavljević and L. S. Pantić, "Investigation of the impact of atmospheric pollutants on solar module energy efficiency", *Therm. Sci.*, vol. 21, no. 5, pp. 2021-2030, 2017.
[48] T. Zhong, Z. Zhang, M. Chen, K. Zhang, Z. Zhou, R. Zhu, Y. Wang, G. Lü and J. Yan, "A city-scale estimation of rooftop solar photovoltaic potential based on deep learning", *Appl. Energy*, vol. 298, p. 117132, 2021.
[49] G. Xexakis and E. Trutnevyte, "Consensus on future EU electricity supply among citizens of France, Germany, and Poland: Implications for modeling", *Energy Strategy Rev.*, vol. 38, p. 100742, 2021.
[50] Electricity price statistics. Data available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics#Electricity_prices_for_non-household_consumers
[51] PVsyst software tool. Available at: https://www.pvsyst.com/download-pvsyst/